इंटरनेट मानक

Disclosure to Promote the Right To Information

Whereas the Parliament of India has set out to provide a practical regime of right to information for citizens to secure access to information under the control of public authorities, in order to promote transparency and accountability in the working of every public authority, and whereas the attached publication of the Bureau of Indian Standards is of particular interest to the public, particularly disadvantaged communities and those engaged in the pursuit of education and knowledge, the attached public safety standard is made available to promote the timely dissemination of this information in an accurate manner to the public.

“जानने का अधिकार, जीने का अधिकार”
Mazdoor Kisan Shakti Sangathan
“The Right to Information, The Right to Live”

“पुराने को छोड नये के तरफ”
Jawaharlal Nehru
“Step Out From the Old to the New”

IS 12937 (1990): Engineering metrology - Methods of testing straightness, flatness and perpendicularity [PGD 25: Engineering Metrology]

“ज्ञान से एक नये भारत का निर्माण”
Satyanarayan Gangaram Pitroda
“Invent a New India Using Knowledge”

Act Number 22 of 2005
The Indian Parliament
RIGHT TO INFORMATION

Made Available By
Public.Resource.Org

“ज्ञान एक ऐसा खजाना है जो कभी चुराया नहीं जा सकता है”
Bhartṛhari—Nītiśatakam
“Knowledge is such a treasure which cannot be stolen”

BLANK PAGE

BRUTUM FULMEN

IGNORANTIA JURIS NON EXCUSAT

PROTECTED BY COPYRIGHT

REAFFIRMED 2004

IS 12937 : 1990

Indian Standard

ENGINEERING METROLOGY — METHODS OF TESTING STRAIGHTNESS, FLATNESS AND PERPENDICULARITY

UDC 531·717·81/·86

© BIS 1991

BUREAU OF INDIAN STANDARDS
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI 110002

June 1991 Price Group 8

Engineering Metrology Sectional Committee, LMD 5

FOREWORD

This Indian Standard was adopted by the Bureau of Indian Standards on 9 April 1990, after the draft finalized by the Engineering Metrology Sectional Committee had been approved by the Light Mechanical Engineering Division Council.

This Indian Standard has been prepared in the light of technical practices prevailing in the country. The purpose of bringing out this standard is to delete the methods of test repeated in individual product standards of precision measuring equipments (while revising them) and in their place give reference to this standard.

In reporting the results of a test or analysis made in accordance with this standard, if the final value, observed or calculated, is to be rounded off, it shall be done in accordance with IS 2 : 1960 'Rules for rounding off numerical values (*revised*)'.

AMENDMENT NO.1 JANUARY 1993
TO
IS 12937 : 1990 ENGINEERING METROLOGY — METHODS OF TESTING STRAIGHTNESS, FLATNESS AND PREPENDICULARITY

(*Page* 2, *clause* 4.2.4) — Insert the following at the end of the clause:

'While testing CI scraped surface, slip gauges of suitable thickness shall be used between ball and scraped surface. The ball shall not touch the scraped surface directly.'

(*Page* 16, *clause* 4.3.4) — Insert the following at the end of the clause:

'While testing CI scraped surface, slip gauges of suitable thickness shall be used between ball and scraped surface. The ball shall not touch the scraped surface directly.'

(LMD 05)

Reprography Unit, BIS, New Delhi, India

Indian Standard

ENGINEERING METROLOGY — METHODS OF TESTING STRAIGHTNESS, FLATNESS AND PERPENDICULARITY

1 SCOPE

1.1 This standard covers the methods of examination of straightness, flatness and perpendicularity.

2 REFERENCES

2.1 The following Indian Standards are necessary adjuncts to this standard:

IS No.	*Title*
2220 : 1990	Engineering metrology—Steel straightedges — Specification (*first revision*)
8000 (Part 1) : 1985	Geometrical tolerancing on technical drawings : Part 1 Tolerances of form orientation, location and run-out and appropriate geometrical definitions (*first revision*)

3 TERMINOLOGY

3.0 For the purpose of this standard, the following definitions shall apply.

3.1 Tolerance on Straightness

The distance between two imaginary parallel straight lines within which the actual profile of the surface is contained [*see also* **14.1** of IS 8000 (Part 1) : 1985].

3.2 Tolerance on Flatness

The maximum permissible distance separating two imaginary parallel planes within which the surface under consideration can just be enclosed [*see also* **14.2** of IS 8000 (Part 1) : 1985].

3.3 Tolerance on Perpendicularity

The maximum permissible distance separating the two imaginary parallel planes within which the surface under consideration can just be enclosed. The imaginary parallel planes are perpendicular to the datum face in question [*see also* **14.8** of IS 8000 (Part 1) : 1985].

4 STRAIGHTNESS AND FLATNESS DETERMINATION

4.1 Instruments Used

Various instruments used for determination of straightness or flatness errors are given below. The selection of the suitable instrument depends on the accuracy required in the measurement is to be carried out and on the size of the test straightedge or surface plate:

a) Surface plate, straightedge, slip gauge, or dial gauge/indicator of known accuracy
b) Comparator stand or beam comparator
c) Precison level or electronic level
d) Autocollimator
e) Three-coordinate measuring machine
f) Laser interferometer

4.2 Straightness Determination (of Straightedge, Surface Plate, etc)

4.2.1 *Comparison with a Surface Plate*

Straightness of a straightedge may be tested by direct comparison with a master surface plate of known accuracy. Place the straightedge with its working edge over the surface plate. Two equal slip gauges should be placed just below the points of best support. The gap between the lower working face of the straightedge and the surface plate can be measured at various points by fitting slip gauges. This is an indication of the degree of parallelism along the length of the straightedge (*see* Fig. 1).

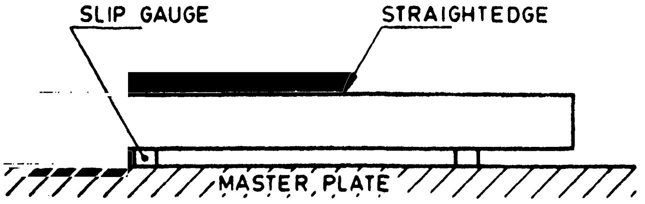


FIG. 1 TESTING OF STRAIGHTEDGE

4.2.1.1 In reviewing the results thus obtained, allowance should be made for the known errors in the surface plate along the direction in which the test was carried out.

4.2.2 *Comparison with a Straightedge*

If a standard steel straightedge of known accuracy complying with IS 2220 : 1962, and length comparable that of the test straightedge is available, it may be used as a basis in conjunction with slip gauges for determining the accuracy of a straightedge under test by direct comparison. The steel straightedge is placed on the working surface of the test straightedge with slip gauges placed under the former under the points of support. A gap is thus formed between the two straightedges. The width of this gap is then measured at desired number of positions by fitting slip gauges into it. The true errors of the working surface of the test straightedge are arrived at after allowing for the errors in the steel straightedge.

Even when the actual errors of the steel straightedge are not known, the method of test may still be used; however it is necessary to repeat the measurements of the gap between the two straightedges after inverting the steel straightedge and to meaure the width of the latter at a number of positions so as to determine any errors of parallelism between its two working edges.

4.2.3 *The Inclination Method or the Step by Step Method*

The instrument used for this purpose should measure very small angular variations of a carriage or block as it is moved step by step along the centre line of the working surface of the straightedge. It may be a spirit level, an electronic level, an autocollimator or any instrument which measures small angular variations. However it is important to note that the weight of the equipment is kept to a minimum in order to avoid distortion of the surface under test.

4.2.3.1 The principle of the method is illustrated in Fig. 2 and the carriage may consist of a plate or block to the underside of which may be fitted (by wringing or otherwise) parallel blocks of equal thickness. These blocks are placed at a separation suited to the step chosen for the measurement and the carriage is moved along the line in steps of this value (Fig. 3). It is also quite satisfactory to use a carriage with feet at a fixed distance, a block level with fixed feet, provided the pitch covered by the feet is suitable for the measurement in hand. In either case, the span may be marked on the feet of the carriage.

4.2.3.2 To carry out a test, the straightedge is placed on a firm support and the working surface under consideration is approximately levelled in both longitudinal and transverse directions. The carriage to be used for making the flatness test is placed at one end of the straightedge with its length in the same direction as the latter. After making the first reading, the carriage is advanced along the straightedge through a distance equal to the span of its feet and a second reading is made. In this way, the carriage is advanced step by step along the straightedge until the other end of the working surface is reached. It is usual to move the carriage backwards over the same path and to obtain a check series of readings terminating at the starting position. The inclination of each span relative to the first setting is thus found and the continuous angular contour recorded. No absolute datum, such as true level is necessary. The datum is the first angular reading, all other inclinations being initially related to this.

Assume, for example, positions *A*, *B*, *C*, *D*, etc, (*see* Fig. 3) laid out 250 mm apart along the centre line of the straightedge. A 250 mm span will also be marked out on the feet or base of the carriage. The first span will be from *A* to *B* and this will be taken as the initial datum from which the other inclinations will be measured. Assume also that the span *B-C* shows an upward tilt of 5 seconds and *C-D* a downward tilt of 2 seconds when the carriage is moved to these positions. On a 250 mm base, one second represents a displacement of 1·2 m; *C* will, therefore, be 6 m above the datum line through *A-B*, and *D* will be 2·4 m below *C* or 3·6 m above the datum, and so on. The end point of the line will generally not be zero although it is usually convenient to take as a datum line the one between the extreme points. The final graphs shall, therefore, be tilted about the origin, either arithmetically or graphically, to bring the end point to zero (Fig. 3).

4.2.3.3 Table 1 shows the method of recording the observations and working up the results. It will be noted that an additional zero is placed above the first reading in col 5; this is because the first reading, although taken as datum zero, represents the relative levels of two points, *A* and *B*. In this case the error at *B* will not, therefore, be zero in col 7 if the graph has to be swung about the origin.

4.2.4 *Testing on a Coordinate Measuring Machine*

Straightness measurement can be conveniently carried out on a three-coordinate measuring machine, if the test item can be accommodated on it.

4.2.5 *Laser Interferometric Method*

Laser interferometer is also capable of making straightness measurement. Its straightness optics forms a highly accurate optical straightedge, which can measure the straightness of travel of machine tool and measuring machine coordinate motions with interferometric accuracy. An example of measurement set up is shown in Fig. 4.

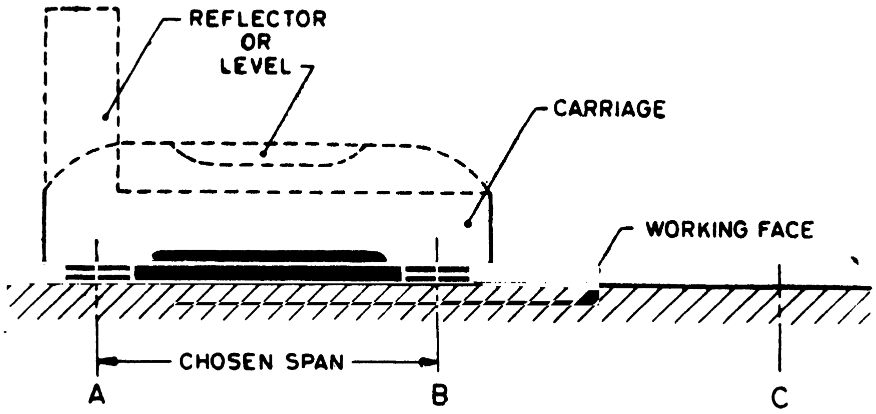


FIG. 2 INCLINATION METHOD OF TESTING STRAIGHTEDGE

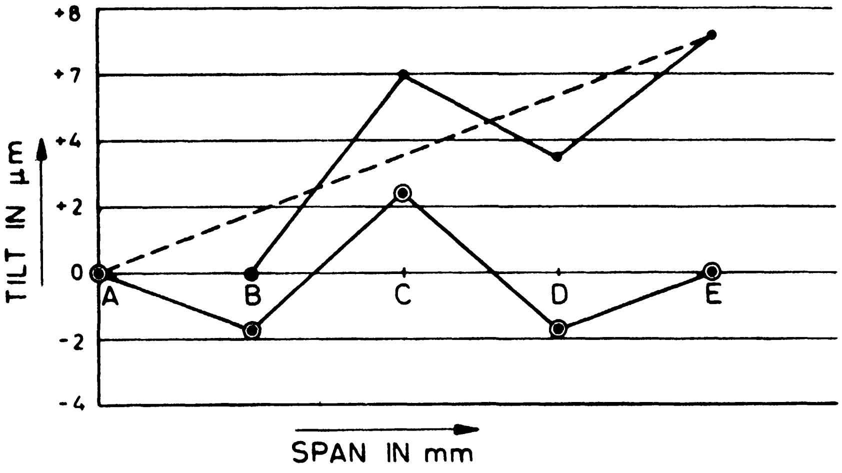


FIG. 3 GRAPHICAL ILLUSTRATION OF TEST

Table 1 Method of Recording the Observations

(*Clause* 4.2.3.3)

Position of Carriage	Angular Reading	Difference from First Reading at Position *AB*	Tilt Over 250 mm Span	Cumulative Deviations from Plane *AB*	Proportional Adjustments to Bring *E* to Zero	Error (Algebraic Sum of col 5 and 6)	Position Along Straight-Edge
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	sec	sec	mm	mm	mm	mm	
—	—	—	—	0	0	0	*A*
AB	15	0	0	0	−1·8	−1·8	*B*
BC	20	+5	+6	+6	−3·6	+2·4	*C*
CD	13	−2	−2·4	+3·6	−5·4	−1·8	*D*
DE	18	+3	+3·6	+7·2	−7·2	0	*E*

NOTE — Although the span used may be of any value within reasonable limits, it is convenient to make it about one-tenth of the length of the straightedge, giving ten steps of measurement.

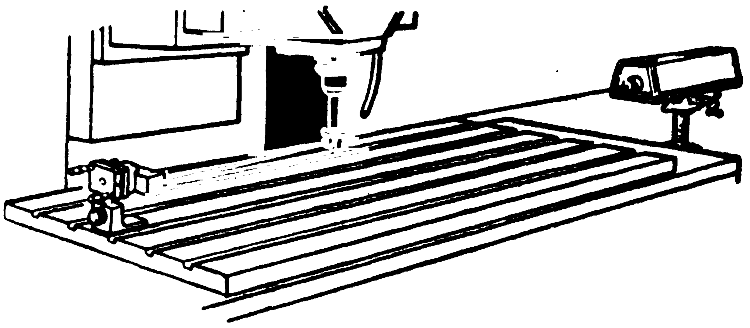


FIG. 4 X-AXIS HORIZONTAL STRAIGHTNESS MEASUREMENT SET

4.3 Flatness Determination (of Surface Plates, Flats, etc)

4.3.1 *Grid Formation*

4.3.1.1 The method of testing large surface plates consists in dividing the entire area of the surface plate into a series of imaginary straight lines forming a grid and determining the straightness of each of these lines. The distance between these lines is decided by the degree of accuracy required; normally it is taken as approximately one-tenth the width of the surface plate, but it is not convenient to use a distance closer than 50 mm. For medium and large surface plates, the extreme outer lines are taken approximately 10 to 20 mm from the outer edges (*see* Fig. 5). The procedure is as follows:

In Fig. 5 the dotted lines represent the imaginary grid lines drawn on the table and along these lines the straightness is measured. The datum plane may be arbitrarily chosen as containing for instance, the points *A*, *B* and *C* so that the points at *A*, *B* and *C* are brought to zero. Taking *AB* as a datum line, the errors at various points along *AB* are measured. Similarly, *AC* and *BC* are taken as datum lines along which the errors are measured. The line joining *A* and *O* is produced to *D*. The errors at *O* and *D* with respect to datum surface are then determined. Taking *D* as a reference point, errors along *BD* and *CD* are determined. This process is continued until all the points of intersection of the grid lines are covered and a contour map of the entire surface is obtained with reference to *ABC* as the datum surface.

4.3.1.2 Alternatively, 8 basic lines grid can be formed as shown in Fig. 6. Instruments and equipments needed for this method are:

a) precision level, electronic level or autocollimator,

b) bridge or mount bracket for mounting of level, mirror, reflector or optical flat, and

c) accurately machined straight steel strip or straightedge for guiding the bridge or mount bracket.

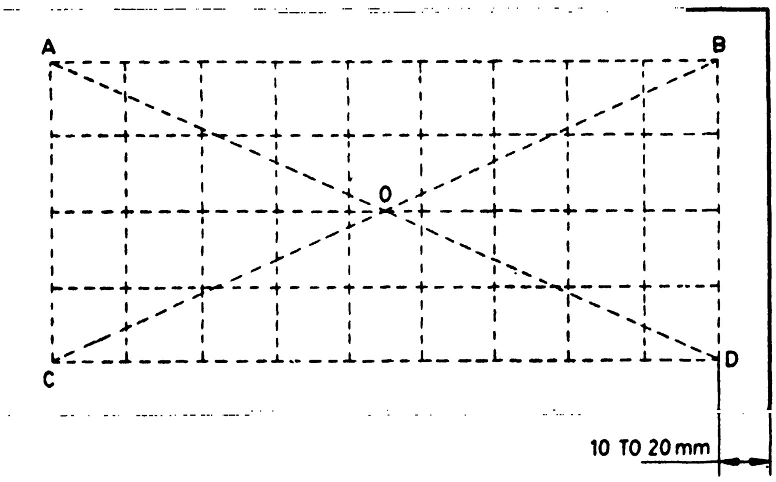


FIG. 5 TESTING OF SURFACE PLATES (GRID METHOD)

The level or reflector in case of autocollimator is mounted on a bridge or a mount bracket, the support pads of which are separated by a distance arbitrarily chosen so that it will divide evenly into dimensions of the surface plate. This distance should be about 8 to 10 percent of the length of the short side of the plate. Various bridges or mount brackets are needed for different size plates. In addition, a straight strip or straightedge, graduated in increments equal to the distance between the support pads of the bridge or mount bracket, is used.

A total of eight lines of reading are taken and marked on surface plate leaving about 20 mm from plate edges, that is four perimeter lines, two diagonal lines and two centre lines, as shown in Fig. 6. It is recommended to punch letters on side edges of surface plate for identification of lines.

The perimeter lines are laid out in one increment from the edge of the plate. The precise stations at which readings along all eight lines taken are measured in steps equal to the increments on the straight strip or straight edge.

The level bridge or reflector mount bracket is moved along the line and readings are taken for each station and for each of the eight lines. When taking readings for diagonal line *AC* starting from *A* and going towards *C* always write *AC* as *A-C* and if it is otherwise write *C-A*. Follow this procedure for all the eight lines. These readings taken for each line and each station are entered directly on the properly identified worksheets, as shown in Table 1. After each line is completed, the level or reflector is moved back to the first station on that line and another reading taken. If this does not agree within ± 3·0 seconds of arc with first reading taken at that same station, the operation must be repeated.

The readings entered on the work sheet show only angular displacement in a second of arc in relation to the line of first reading (in autocollimators or electronic levels, now available, the angular displacement could be in tenths of a second of arc). To be readily meaningful, these must be converted to linear deviations from base plane. The procedure for these conversions and their presentation is discussed in the specimen example.

4.3.2 *Comparative Method with a Beam Comparator*

4.3.2.1 The general degree of flatness of a surface plate may be quickly and accurately compared with that of a master plate of the same size or larger by the use of a beam comparator of the type shown in Fig. 7. Having set the distance between the two outer legs to the maximum dimensions of the plate to be tested, the beam comparator is placed first on the master plate and then on the one to be tested, the indicator being read on each occasion. Any difference in the two readings is a direct measurement of the error in the plate under test over the span used.

4.3.2.2 For this type of comparative test it is not essential that the master plate itself should be absolutely true, provided its error is known even along the one line where the beam comparator is set; this error may be adjusted in the final result.

4.3.3 *Alternate Method Using Precision Level or Autocollimator*

A precision level or an electronic level or the mirror in case of an autocollimator is mounted on a suitable bridge as shown in Fig. 8. The centre part of the bearing areas at both the ends of the bridge may be relieved if necessary to provide for proper seating. The distance *X* (*see* Fig. 8A) between the two bearing areas of the bridge is chosen to suit the inspection requirements. (The bridge used in the specimen example has *X* equal to 100 mm.)

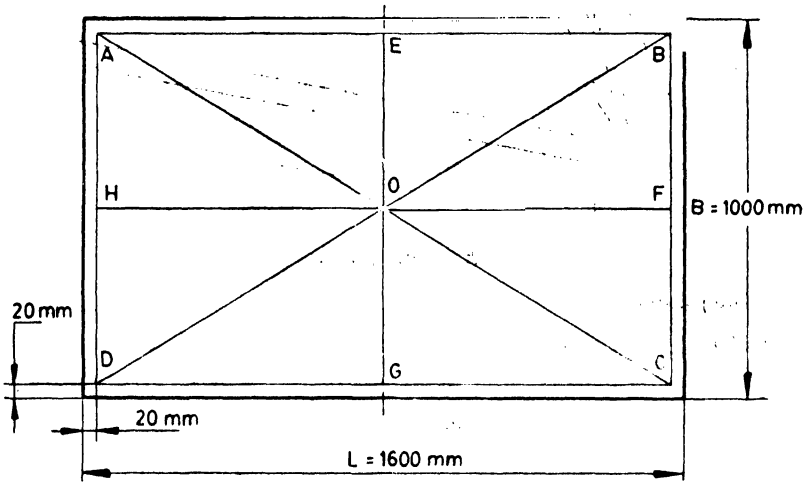
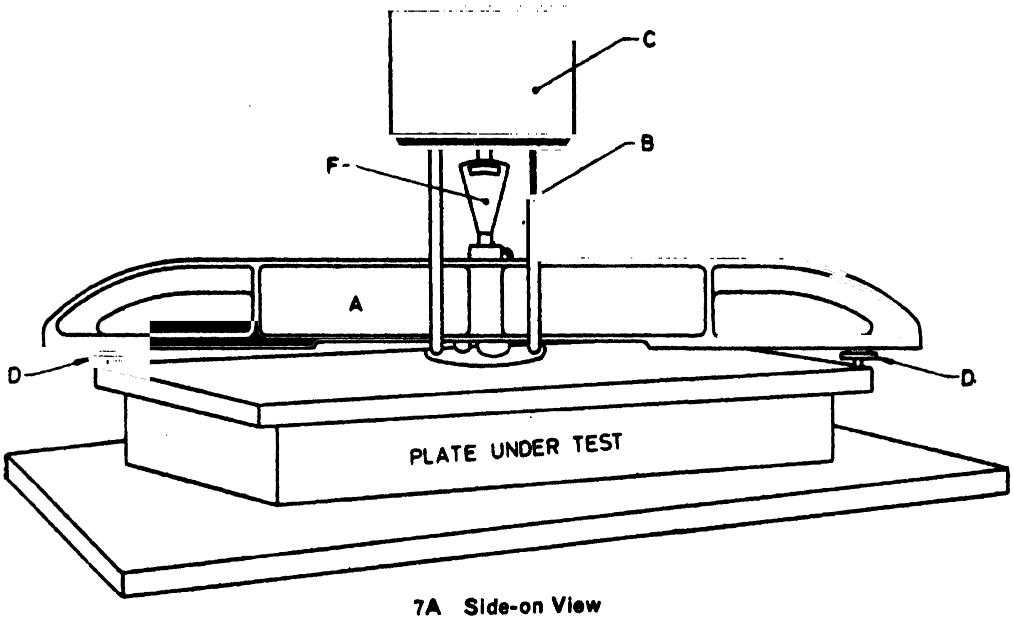
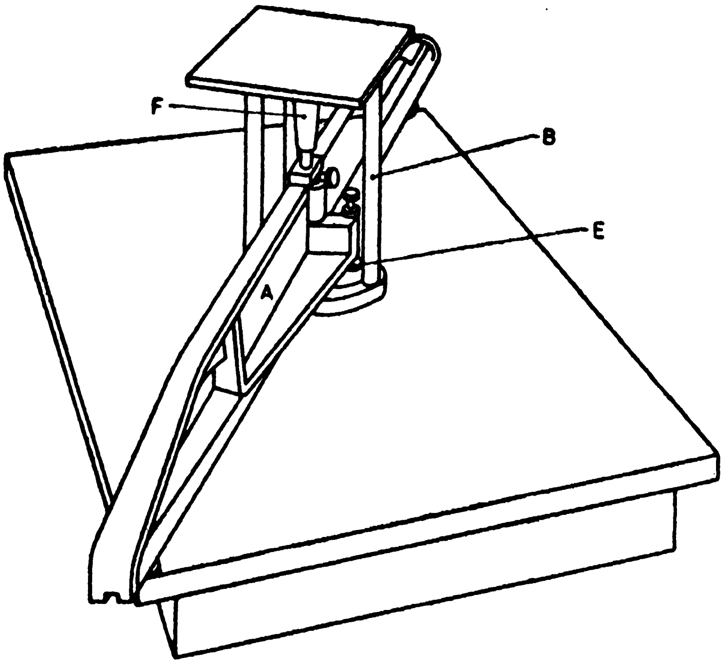


Fig. 6 Eight Principal Lines Grid



7A Side-on View



7B End-on View

A — Beam comparator

B — Central mass support

C — Masses for application of load

D — Supporting feet (two)

E — Third foot (Offset)

F — Sensitive indicator

FIG. 7 TEST APPARATUS FOR RIGIDITY TEST

The surface plate is approximately levelled using the engineers level by positioning it in two mutually perpendicular positions in the middle as shown in Fig. 8B.

4.3.3.1 *Specimen example with grid pattern (given in* **4.3.1.1**)

The surface plate is divided into small squares of 100 mm or any other convenient size, as shown in Fig. 8C. The bridge is used in such a way (*see* Fig. 8D) that when the bearing areas of the bridge scan the centres of areas A_1 and A_2, then the reading indicate the difference in height between A_1 and A_2. Similarly, the difference in level between A_2 and A_3 and so on up to A_4 and A_5 are tabulated as shown in Fig. 8E. The readings of row *A* are thus completed. The level then is positioned on the centres of areas A_1 and B_1 and the readings noted which gives the difference in height between A_1 and B_1. Now the readings of row *B* are taken scanning the centres of areas B_1, B_2, B_3 and so on which gives the reading of row *B*. Further readings are completed for all the rows and the readings are tabulated as shown in Fig. 8E.

Since A_1 is the datum point, the reading at A_1 is taken as zero. With the help of these readings the cumulative values, that is, errors at various points are reduced with reference to the datum A_1 by taking the algebraic sum of the individual differences, as indicated in Fig. 8F. This table gives the linear heights of the surface from a plane passing through the first square *A*, whose value is zero. However, if required, readings may be taken in any other column such as the middle or the last column for cross checking.

The error of flatness is defined as the minimum distance between two parallel planes, one passing through the topmost point(s) of the profile and the other passing through the bottommost point(s) of the profile. This is explained in Fig. 9A as applicable for straightness. The same principle is extended for flatness. From actual readings it is, therefore, necessary to visualize two parallel planes and reorient them in such a way that the difference between the maximum and the minimum of the computed values gives the minimum distance between them. If necessary, the plane of the working surface may be inclined in a convenient position and the difference computed. This can be done either mathematically which is quite complicated or by a simple method as described below.

This is easily understood by following the specimen calculation as referred to readings obtained on a 1 000 mm × 630 mm granite surface plate. Figure 9B gives the actual readings while Fig. 9C gives the cumulative values. After reorienting the planes, the values are retabulated as in Fig. 10A and Fig. 10B for directions *DA* and *AB*. From the finally computed values the difference in the maximum and the minimum indicates the actual error of flatness. The zero reference line in this example is chosen at area A_1 (*see* Fig. 8C), but this may be taken in any column or row depending upon the type of the surface. In such a case the adding or the subtracting value start with, say, $+3+2+1+0-1-2$. This manipulation is carried out till we get the minimum difference between the highest and the lowest value(s).

4.3.3.2 *Specimen example with grid pattern given in* **4.3.1.2**

Directions for converting readings taken for each of eight principal lines (*see* Fig. 6) into linear displacement in microns are given without any attempt at theoretical justification. One line of each class is explained in detail with the help of work sheets in Table 2.

For each of the eight lines, the stations at which readings were taken are identical in column 1 in terms of millimetres from the edge of the plate in the direction in which the line was read.

The instrument readings are entered in column 2. No reading is entered for the first station on the line.

Conversion for Diagonals: *AC* and *DB*:

To process the *AC* diagonal line data, the following steps should be taken in the order (sequence) given below:

a) Convert the instrument readings into angular displacement by determining the amount by which each value in column 2 is greater or less than the first value in column 2. Do this at each station, enter the result in column 3, paying attention to the sign.

b) Next determime the algebraic sum of the angular displacement at each station and enter this value in column 4. To do this, add the values in column 3 down to and including each station.

c) Divide the last value in column 4 by the total number minus one of the stations on the line to determine the correction factor. (In the example shown, there are 13 stations. Hence correction factor for diagonal $AC = 6/12 = +0{\cdot}50$.)

d) Set up arithmetic progression in column 5. Reverse the sign of the value in column 4 opposite the midstation and enter it opposite the same station in column 5. Working up column 5 from the midstation, add the correction factor cumulatively at each station. Return to the midstation and subtract the correction factor cumulatively at each station to the bottom of the column. The resulting arithmetical progression is the cumulative correction factor for each station.

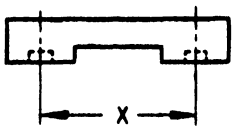


FIG. 8A

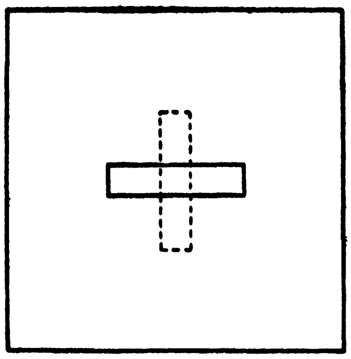


FIG.8B

E_1	E_2	E_3	E_4	E_5
D_1	D_2	D_3	D_4	D_5
C_1	C_2	C_3	C_4	C_5
B_1	B_2	B_3	B_4	B_5
A_1	A_2	A_3	A_4	A_5

FIG.8C

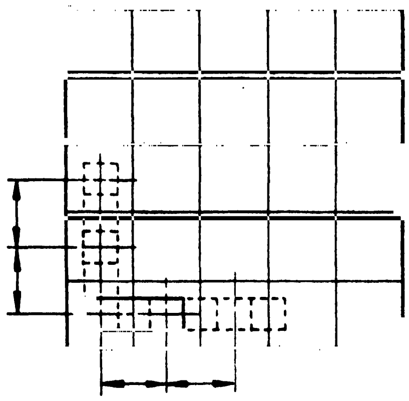


FIG.8D

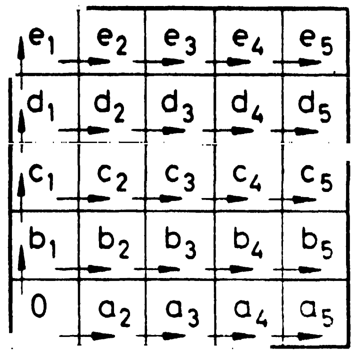
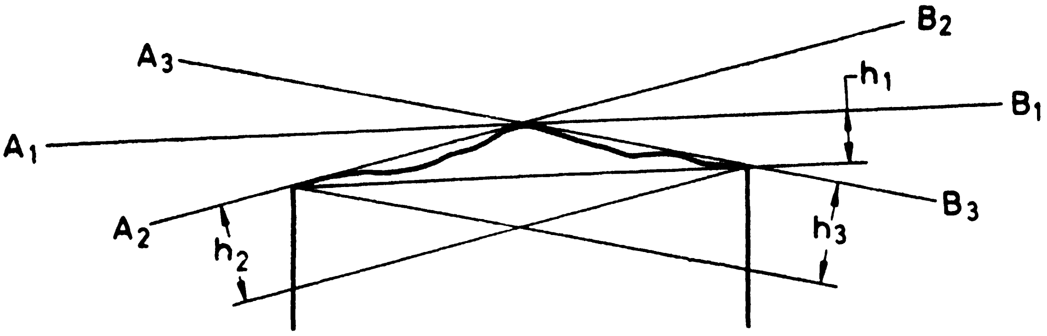


FIG.8E

$b_1+c_1+d_1+e_1$	$b_1+c_1+d_1+e_1$ $+e_2$	$b_1+c_1+d_1+e_1$ $+e_2+e_3$	$b_1+c_1+d_1+e_1$ $+e_2+e_3+e_4$	$b_1+c_1+d_1+e_1$ $+e_2+e_3+e_4+e_5$
$b_1+c_1+d_1$	$b_1+c_1+d_1+d_2$	$b_1+c_1+d_1+d_2$ $+d_3$	$b_1+c_1+d_1+d_2$ d_3+d_4	$b_1+c_1+d_1+d_2$ $+d_3+d_4+d_5$
b_1+c_1	$b_1+c_1+c_2$	$b_1+c_1+c_2+c_3$	$b_1+c_1+c_2+c_3$ $+c_4$	$b_1+c_1+c_2+c_3$ $+c_4+c_5$
b_1	b_1+b_2	$b_1+b_2+b_3$	$b_1+b_2+b_3+b_4$	$b_1+b_2+b_3+b_4$ $+b_5$
0	a_2	a_2+a_3	$a_2+a_3+a_4$	$a_2+a_3+a_4+a_5$

FIG. 8F

Fig. 8 Alternate Method for Testing Surface Plate Using Spirit Level



POSSIBLE ORIENTATIONS OF THE IDEAL SURFACE:
A_1-B_1; A_2-B_2; A_3-B_3

CORRESPONDING DISTANCES:
h_1 ; h_2 ; h_3

OF THESE h_1 IS THE MINIMUM. THEREFORE, THE ORIENTATION OF THE IDEAL SURFACE IS A_1-B_1, AND h_1 IS TO BE EQUAL TO OR LESS THAN THE SPECIFIED TOLERANCE.

FIG. 9A

A B

-1.8	+0.2	+0.1	0	-0.1	-0.2	-0.1	+0.4	+0.5	+0.1
-1	-0.3	-0.9	-0.8	+0.2	+0.1	0	+0.2	-0.2	+0.8
-1	-0.2	-0.9	-1	-0.5	0	0	+0.6	+0.2	+1.3
-2	-0.2	-0.8	-1.2	-1	-0.3	-0.2	+0.9	+1.2	+1.5
-1	-1.1	-0.9	-1.4	-0.9	-0.2	+0.1	+0.4	+1	+0.2
0	-1.5	-0.2	-2	-0.4	+0.5	-0.2	+0.8	+0.7	-0.5

D C

FIG. 9B

A B

-6.8	-6.6	-6.5	-6.5	-5.6	-6.8	-6.9	-6.5	-6	-5.9
-5	-5.3	-6.2	-7	-6.8	-6.7	-6.7	-6.5	-6.7	-5.9
-4	-4.2	-5.1	-6.1	-6.6	-6.6	-6.6	-6	-5.8	-4.5
-3	-3.2	-4	-5.2	-6.2	-6.5	-6.7	-5.8	-4.6	-3.1
-1	-2.1	-3	-4.4	-5.3	-5.5	-5.4	-5	-4	-3.8
0	-1.5	-1.7	-3.7	-4.1	-3.6	-3.8	-3	-2.3	-2.8

D C

FIG. 9C

All values in µm.

FIG. 9 ALTERNATE METHOD FOR TESTING SURFACE PLATE USING SPIRIT LEVEL

A B

5	-1.8	-1.6	-1.5	-1.5	-1.6	-1.8	-1.9	-1.5	-1	-0.9
4	-1	-1.3	-2.2	-3	-2.8	-2.7	-2.7	-2.5	-2.7	-1.9
3	-1	-1.2	-2.1	-3.1	-3.6	-3.6	-3.6	-3	-2.8	-1.5
2	-1	-1.2	-2	-3.2	-4.2	-4.5	-4.7	-3.8	-2.6	-1.1
1	0	-1.1	-2	-3.4	-4.3	-4.5	-4.4	-4	-3	-2.8
0	0	-1.5	-1.7	-3.7	-4.1	-3.6	-3.8	-3	-2.3	-2.8

D C

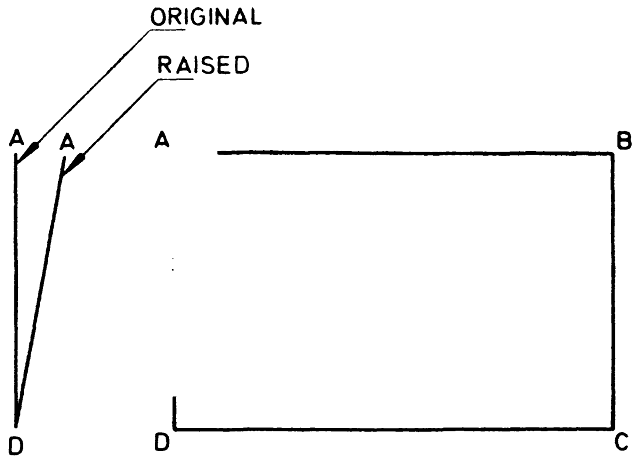


FIG.10A WORK SURFACE PLANE RAISED BY 0,1,2,3,4,5 IN DIRECTION DA (CB)

A B

0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
-1.8	-1.5	-1.3	-1.2	-1.2	-1.3	-1.3	-0.8	-0.2	0
-1	-1.2	-2	-2.7	-2.4	-2.2	-2.1	-1.8	-1.9	-1
-1	-1.1	-1.9	-2.8	-3.2	-3.1	-3	-2.3	-2	-0.6
-1	-1.1	-1.8	-2.9	-3.8	-4	-4.1	-3.1	-1.8	-0.2
0	-1	-1.8	-3.1	-3.9	-4	-3.8	-3.3	-2.2	-1.9
0	-1.4	-1.5	-3.4	-3.7	-3.1	-3.2	-2.3	-1.5	-1.9

D C

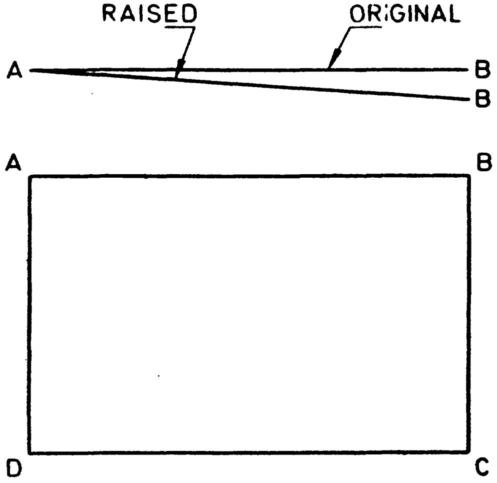


FIG.10B WORK SURFACE PLANE RAISED BY 0,0.1,0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8 AND 0.9 IN DIRECTION AB (DC)

Extreme values are 0 and 4·1. Therefore, error of flatness = 4·1 µm ≈ 5 µm.

All values in µm.

FIG. 10 ALTERNATE METHOD FOR TESTING SURFACE PLATE

e) At each station, add algebraically the values in columns 4 and 5 enter the sum which is the angular displacement from the datum plane in column 6. [The datum plane (*see* Fig. 11A) is that plane in which the centre point of the surface plate lies and is parallel to the lines containing the end points of each diagonal.] Proceed with the other diagonal *D-B* in exactly the same way to this point. Before the last two columns for the diagonals can be completed, computation for the perimeter and centre lines must be carried to this point. Do the perimeter lines next.

Conversion for Perimeter lines — Perimeter Line *AB*:

i) Proceed exactly as with the diagonal through column 4 for each of the perimeter line.

ii) Prepare a chart of the surface plate as illustrated in Fig. 13. Enter the physical centre 0 and the values found for the ends of the diagonal from column 6 in the work sheet as shown. This chart is important as without it there is danger of confusing the figures.

iii) Enter the value for the *A* and in columns 5 and 6 opposite the first station. Enter the value of the *B* and opposite the last station in column 6 only.

iv) Next find the correction factor. Subtract the value opposite the last station in column 4 from the value opposite the same station in column 6 [—1 — (+6) = —7]. Enter this value opposite the last station in column 6. Subtract this value from that opposite the first station in column 5 [—1·0 — (—7·0) = +6] and divide the result by the total number of stations on the line minus one (+ 6/10 = +0·60). The result is the correction factor.

v) Beginning at the last station in column 5, add the correction factor cumulatively up the column at each station.

vi) To find the angular displacement from the datum plane, algebraically add the values opposite each station in columns 4 and 5 and enter the results in column 6. Complete the conversion for each of the perimeter lines to this point and enter the values at the midpoints in Fig. 12. Now proceed with the centre lines.

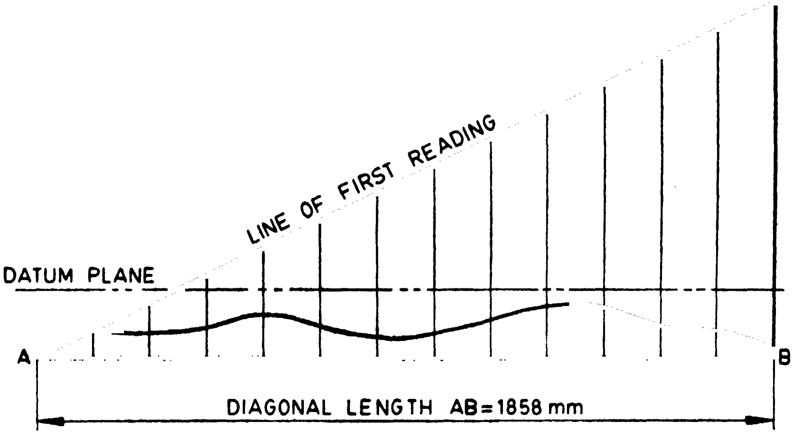


FIG. 11 DIAGRAM SHOWING RELATIONSHIP OF PROFILE OF DIAGONAL *AB* TO LINE OF FIRST READING AND DATUM PLANE

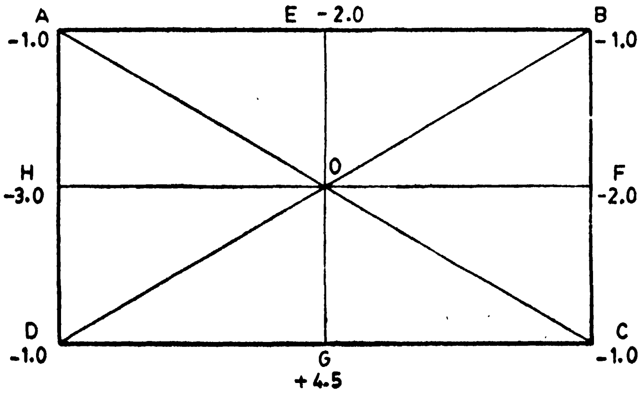


FIG. 12 DATA REDUCTION WORK SKETCH FOR DETERMINING CORRECTION FACTORS AND DISPLACEMENTS FROM DATUM PLANE

Conversions for *H-F* Centre Line

1. i) Carry the conversion through column 4. The procedure for the centre lines is exactly the same as for the diagonals and perimeter lines to this point.
2. ii) From Fig. 13 enter the value for the midpoint of the perimeter line *AB* opposite the first station in columns 5 and 6. Enter the value for the midpoint of the perimeter line *BC* opposite the last station in column 6 only.
3. iii) Subtract the value opposite the last station in column 4 from the value opposite the same station in column 6 and enter this value at the last station in column 5.
4. iv) Subtract the last value in column 5 from the first and divide the result by the total number of stations on the line minus one. The result is the correction factor.
5. v) Beginning at the last station in column 5, add the correction factor up the column in an arithmetic progression to find the cumulative correction factor for each station.
6. vi) At each station, add algebraically the values in columns 4 and 5 and enter the result in column 6. This is the angular displacement from the datum plane.
7. vii) Change the sign of the value opposite the midstation in column 6 and add it to the value opposite each station in column 6. Enter the sums in column 6a.

A word of explanation is necessary at this point. The center line check is the criterion of accuracy for the entire operation. The value at the point at which the centre lines and diagonals intersect is physically zero. If everything was done perfectly the value opposite the centre stations would be zero. But this is not possible because each slight error in reading the instrument is reflected at the midstation of the centre lines. If the magnitude of this error is under 2·5 microns, the calibration may be regarded as satisfactory; if not the job must be done over.

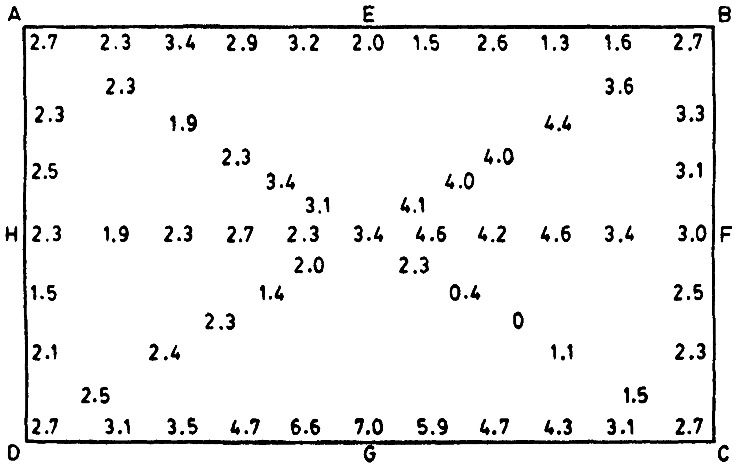
Column 6a, which appears only in the work sheets for the centre lines, is used to move the error away from the centre, which is known to be zero, out to the perimeter.

Final Step in Conversion

The work sheets for the eight lines are now completed through column 6, including column 6a, for the centre lines.

The procedure for columns 7 and 8 is identical for all work sheets and must be done together.

1. i) Search through column 6 for all work sheets, column 6a of the centre lines, for the lowest value in all the 8 columns. Add this value to the value opposite each station in column 6 (6a for the centre lines) and enter the sums in column 7. This figure is the angular displacements in arc seconds from the true base plane. This is defined as the plane containing the point of lowest reading and parallel to the datum plane.
2. ii) Next, convert the values in column 7 to linear values in microns. To do this multiply the product of the sine of 1 second (0·000 005) times the distance between the centre lines of the bridge or mount brackets, say, for example, for diagonals *AC* and *BD* bridge support is 152·5 mm then multiplying factor for diagonals shall be 152·5 × 0·000 005 = 0·000 762 5 mm or say, 0·76 microns, by the values in column 7 at each station. Round off the answer to the nearest one tenth micron and enter the value in column 8. Likewise carry out conversion for perimeter lines and centre lines and enter values in column 8.



NOTE — Figure represents height from base plane in microns. All points lie between two parallel planes 7·0 microns apart.

FIG. 13 LINEAR DEVIATIONS FROM BASE PLANE INDICATED ALONG THE EIGHT PRINCIPAL LINES OF A 1 600 mm × 1 000 mm SIZE SURFACE PLATE

Table 2 Work Sheet for Calibrating a 1 600 × 1 000 mm Surface Plate

(*Clause* 4.3.3.2)

Station (mm from Edge) (1)	Instrument Readings Arc Sec (2)	Angular Displacement Arc Sec (3)	Sum of Displacement Arc Sec (4)	Cumulative Correction Factor Arc Sec (5)	Displacement from Datum Plane Arc Sec (6)	Displacement from Base Plane Arc Sec (7)	Displacement from Base Plane (0·001 mm) (8)
			Diagonal *AC*				
28·0	0	0	0	− 1·0	− 1·0	3·5	2·70
180·5	8·0	0	0	− 1·5	− 1·5	3·0	2·3
333·0	8·0	0	0	− 2·0	− 2·0	2·5	1·9
485·5	9·0	+ 1·0	+ 1·0	− 2·5	− 1·5	3·0	2·3
638·0	10·0	+ 2·0	+ 3·0	− 3·0	0	4·5	3·4
790·5	8·0	0	+ 3·0	− 3·5	− 0·5	4·0	3·1
943·0	9·0	+ 1·0	+ 4·0	− 4·0	0	4·5	3·4
1 095·5	7·0	− 1·0	+ 3·0	− 4·5	− 1·5	3·0	2·3
1 248·0	6·0	− 2·0	+ 1·0	− 5·0	− 4·0	0·5	0·4
1 400·5	8·0	0	+ 1·0	− 5·5	− 4·5	0	0
1 553·0	10·0	+ 2·0	+ 3·0	− 6·0	− 3·0	1·5	1·1
1 705·5	9·0	+ 1·0	+ 4·0	− 6·5	− 2·5	2·0	1·5
1 858·0	10·0	+ 2·0	+ 6·0	− 7·0	− 1·0	3·5	2·70
	$\frac{+6}{12} = +0·50$						
			Diagonal *BD*				
28·0	0	0	0	− 1·0	− 1·00	3·5	2·70
180·5	10·0	0	0	+ 0·17	+ 0·17	4·67	3·60
330·0	10·0	0	0	+ 1·33	+ 1·33	5·83	4·40
485·5	8·0	− 2·0	− 2·0	+ 2·50	+ 0·50	5·00	4·0
638·0	9·0	− 1·0	− 3·0	+ 3·67	+ 0·67	5·17	4·0
790·5	9·0	− 1·0	− 4·0	+ 4·83	+ 0·83	5·33	4·1
943·0	8·0	− 2·0	− 6·0	+ 6·0	0	4·50	3·4
1 095·5	7·0	− 3·0	− 9·0	+ 7·17	− 1·83	2·67	2·0
1 248·0	8·0	− 2·0	− 11·0	+ 8·33	− 2·67	1·83	1·4
1 400·5	10·0	0	− 11·0	+ 9·50	− 1·50	3·00	2·3
1 553·0	9·0	− 1·0	− 12·0	+ 10·67	− 1·33	3·17	2·4
1 705·5	9·0	− 1·0	− 13·0	+ 11·83	− 1·17	3·33	2·5
1 858·0	9·0	− 1·0	− 14·0	+ 13·00	− 1·00	3·50	2·70
	$\frac{-14·0}{12} = -1·17$						

(*Continued*)

Table 2 (*continued*)

Station (mm from Edge) (1)	Instrument Readings Arc Sec (2)	Angular Displacement Arc Sec (3)	Sum of Displacement Arc Sec (4)	Cumulative Correction Factor Arc Sec (5)	Displacement from Datum Plane Arc Sec (6)	Displacement from Base Plane Arc Sec (7)	Displacement from Base Plane (0·001 mm) (8)
			Perimeter Line AB				
20·0	0	0	0	− 1·0	− 1·0	3·50	2·70
176·0	8	0	0	− 1·6	− 1·6	2·90	2·30
332·0	10·0	+ 2·0	+ 2·0	− 2·2	− 0·2	4·30	3·40
488·0	8·0	0	+ 2·0	− 2·8	− 0·8	3·70	2·90
644·0	9·0	+ 1·0	+ 3·0	− 3·4	− 0·4	4·1	3·20
800·0	7·0	− 1·0	+ 2·0	− 4·0	− 2·0	2·5	2·00
956·0	8·0	0	+ 2·0	− 4·6	− 2·6	1·9	1·50
1112·0	10·0	+ 2·0	+ 4·0	− 5·2	− 1·2	3·3	2·60
1268·0	7·0	− 1·0	+ 3·0	− 5·8	− 2·8	1·7	1·30
1424·0	9·0	+ 1·0	+ 4·0	− 6·4	− 2·4	2·1	1·60
1580·0	10·0	+ 2·0	+ 6·0	− 7·0	− 1·0	3·5	2·70
	$\frac{-1{\cdot}0-(-7{\cdot}0)}{10}=\frac{+6}{10}=+0{\cdot}60$						
			Perimeter Line DC				
20·0	0	0	0	− 1·0	− 1·0	3·5	2·70
176·0	10·0	0	0	− 0·5	− 0·5	4·0	3·10
332·0	10·0	0	0	0	0	4·5	3·50
488·0	11·0	+ 1·0	+ 1·0	+ 0·5	+ 1·5	6·0	4·70
644·0	12·0	+ 2·0	+ 3·0	+ 1·0	+ 4·0	8·5	6·60
800·0	10·0	0	+ 3·0	+ 1·5	+ 4·5	9·0	7·00
956·0	8·0	− 2·0	+ 1·0	+ 2·0	+ 3·0	7·5	5·90
1 112·0	8·0	− 2·0	− 1·0	+ 2·5	+ 1·5	6·0	4·70
1 268·0	9·0	− 1·0	− 2·0	+ 3·0	+ 1·0	5·5	4·30
1 424·0	8·0	− 2·0	− 4·0	+ 3·5	− 0·5	4·0	3·10
1 580·0	9·0	− 1·0	− 5·0	+ 4·0	− 1·0	3·5	2·70
	$\frac{-1{\cdot}0-(+4{\cdot}0)}{10}=\frac{-5}{10}=-0{\cdot}5$						
			Perimeter Line AD				
20·0	0	0	0	− 1·0	− 1·0	3·50	2·80
180·0	8·0	0	0	− 1·67	− 1·67	2·83	2·30
340·0	9·0	+ 1·0	+ 1·0	− 2·33	− 1·33	3·17	2·50
500·0	7·0	− 1·0	0	− 3·0	− 3·0	1·50	1·20
660·0	9·0	+ 1·0	+ 1·0	− 3·67	− 2·67	1·83	1·50
820·0	10·0	+ 2·0	+ 3·0	− 4·93	− 1·93	2·57	2·10
980·0	9·0	+ 1·0	+ 4·0	− 5·0	− 1·0	3·50	2·80
	$\frac{-1{\cdot}0-(-5{\cdot}0)}{6}=\frac{+4{\cdot}0}{6}=+0{\cdot}67$						

(*Continued*)

Table 2 (*concluded*)

Station (mm from Edge)	Instrument Readings Arc Sec	Angular Displacement Arc Sec	Sum of Displacement Arc Sec	Cumulative Correction Factor Arc Sec	Displacement from Datum Plane Arc Sec	Displacement from Base Plane Arc Sec	Displacement from Base Plane (0·001 mm)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Perimeter Line *BC*							
20·0	0	0	0	− 1·0	− 1·00	3·50	2·80
180·0	10·0	0	0	− 0·33	− 0·33	4·17	3·30
340·0	9·0	− 1·0	− 1·0	+ 0·33	− 0·67	3·83	3·10
500·0	8·0	− 2·0	− 3·0	+ 1·00	− 2·0	2·50	2·00
660·0	10·0	0	− 3·0	+ 1·67	− 1·33	3·17	2·50
820·0	9·0	− 1·0	− 4·0	+ 2·33	− 1·67	2·83	2·80
980·0	10·0	0	− 4·0	+ 3·0	− 1·0	3·50	2·80

$$\frac{-1{\cdot}0-(+3{\cdot}0)}{6}=\frac{-4{\cdot}0}{6}=0{\cdot}67$$

Centre Line *EG*

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
20·0	0	0	0	− 2·0	− 2·0	− 2·75	1·75	1·40
180·0	8·0	0	0	− 2·08	− 2·08	− 2·83	1·67	1·80
340·0	9·0	+ 1·0	+ 1·0	− 2·17	− 1·17	− 1·92	2·58	2·00
500·0	10·0	+ 2·0	+ 3·0	− 2·25	+ 0·75	0	4·50	3·60
660·0	10·0	+ 2·0	+ 5·0	− 2·33	+ 2·67	+ 1·92	6·42	5·10
820·0	8·0	0	+ 5·0	− 2·42	+ 2·58	+ 1·83	6·33	5·10
980·0	10·0	+ 2·0	+ 7·0	− 2·5	+ 4·5	+ 3·75	8·25	6·60

$$\frac{-2{\cdot}0-(-2{\cdot}5)}{6}=\frac{+0{\cdot}5}{6}=+0{\cdot}0833$$

Centre Line *HF*

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
20·0	0	0	0	− 3·0	− 3·0	− 1·5	3·0	2·3
176·0	8·0	0	0	− 3·5	− 3·5	− 2·0	2·5	1·9
332·0	9·0	+ 1·0	+ 1·0	− 4·0	− 3·0	− 1·5	3·0	2·3
488·0	9·0	+ 1·0	+ 2·0	− 4·5	− 2·5	− 1·0	3·5	2·7
644·0	8·0	0	+ 2·0	− 5·0	− 3·0	− 1·5	3·0	2·3
800·0	10·0	+ 2·0	+ 4·0	− 5·5	− 1·5	0	4·5	3·4
956·0	10·0	+ 2·0	+ 6·0	− 6·0	0	+ 1·5	6·0	4·6
1 112·0	8·0	0	+ 6·0	− 6·5	− 0·5	+ 1·0	5·5	4·2
1 268·0	9·0	+ 1·0	+ 7·0	− 7·0	0	+ 1·5	6·0	4·6
1 424·0	7·0	+ 1·0	+ 6·0	− 7·5	− 1·5	0	4·5	3·4
1 580·0	8·0	0	+ 6·0	− 8·0	− 2·0	− 0·5	4·0	3·0

$$\frac{-3{\cdot}0-(-8{\cdot}0)}{10}=\frac{+5{\cdot}0}{10}=+0{\cdot}5$$

Maximum deviation in DC 6 = 7·0 **microns**
Closing error in HF = 1·1 **microns**
Closing error in FG = 0·8 **microns**

Conclusion

The data from column 8 when reported on the form shown in Fig. 13 allows the user to see at a glance the features of the surface plate he is using. It shows not only the extremes of variation, but also the best areas on the plate.

4.3.4 *Testing on a Coordinate Measuring Machine*

Flatness measurement using the grid methods shown in **4.3.1** and **4.3.2** may be conveniently carried out on a three-coordinate measuring machine, if the test surface plate can be accommodated on it.

4.3.5 *Laser Interferometric Method*

Laser interferometer with its angular optics and flatness accessory kit is capable of measuring the flatness of surface plates or machine tool beds. Measurement set up for a surface plate calibration is shown in Fig. 14.

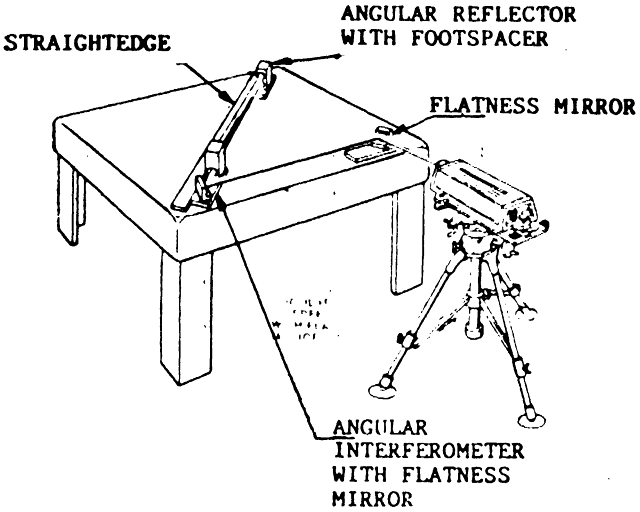

ANGULAR REFLECTOR WITH FOOTSPACER
STRAIGHTEDGE
FLATNESS MIRROR
ANGULAR INTERFEROMETER WITH FLATNESS MIRROR

FIG. 14 LASER INTERFEROMETRIC METHOD

4.3.6 *Flatness of Small Surfaces*

A sensitive method of checking the flatness of a surface which has been lapped and polished is by means of an optical flat or a gauge block interferometer, making use of the phenomenon of optical interference. With monochromatic light, the interference patterns formed are true contour maps of the surface, a few typical patterns are shown in Fig. 15.

4.4 Computer Analysis

Modern coordinate measuring machines and laser measurement systems are equipped with computer that gather, analyse, plot and store straightness/flatness measurement data.

5 PERPENDICULARITY DETERMINATION

5.1 Instruments Used

5.1.1 Tested known accuracy cylindrical square, engineer's square or block square, surface plate or toolmaker's flat and slip gauges.

5.1.2 *Squareness Tester and Tested Known Accuracy Square*

5.1.3 *Autocollimator and Optical Square*

5.1.4 *Coordinate Measuring Machine*

5.1.5 *Laser Interferometer*

5.2 Perpendicularity Determination Methods

5.2.1 *Comparison with a Standard Square*

For testing a square the reference cylinder (or block) and the square are stood side by side on a tested surface plate of known accuracy. The square is slid gently into contact with one side of the cylinder (or block) and the fit between the latter and the outer edge of the square is sighted against a well illuminated background. If a tapering slit of light is seen, the magnitude of the error present in the square can be ascertained by tilting it with gauge blocks inserted under the two ends of the stock until a light-tight fit is achieved from top to bottom of the blade. The error can then be found from the difference between the two gauge blocks and their distance apart.

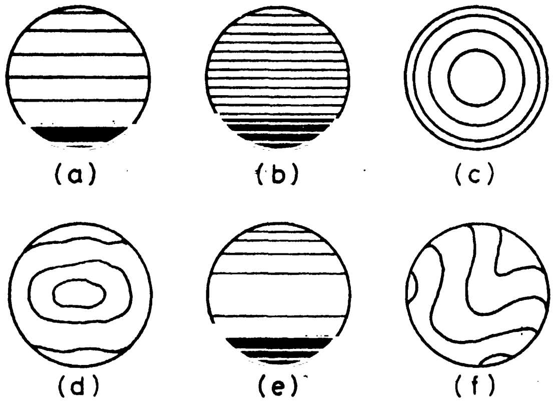


FIG. 15 TYPICAL INTERFERENCE PATTERNS

5.2.2 *Testing on a Squareness Tester*

The perpendicularity of a block square can be tested on a Grade 1 surface plate by means of a simple form of 'squareness tester' (*see* Fig. 16). This consists of a rigid angle block, the vertical arm of which is fitted with a transverse straightedge near the bottom and a sensitive indicator towards the top. By this means, any out-of-squareness of face B_1 with respect to faces A_1 and A_2 can be determined by taking the mean of readings on B_1 with the block standing first on A_1 and then on A_2. After checking B_1 for perpendicularity, B_2 may also be checked. It may be mentioned that any error in the perpendicularity of the block is revealed two-fold by the indicator of the squareness tester.

5.2.3 *Testing on a Tilting Square Tester*

A method of testing an engineers' try square without reference to a block square or master square of any sort is by means of a truly parallel sided straightedge *A* (*see* Fig. 17), held upright on *A* grade surface plate in a tiltable support that permits the straightedge to be slightly inclined in its own plane on either side of the perpendicular. The square, *S*, to be tested is stood along side the straightedge and the perpendicularity of the latter is adjusted by a vertical micrometer screw, *B*, which forms one of the three feet of the support, until there is a light-tight fit between the outer edge of the blade and the adjacent side of the straightedge. The square is then transferred to the other edge of the straightedge. If a light-tight fit is also obtained against this edge of the straightedge, the square is quite true. On the other hand, if a tapered slit of light is seen against the second edge, the direction of the error in the square becomes immediately apparent. The magnitude of the error is shown two fold. It can be measured very accurately by readjusting the micrometer *B*, so as to obtain a light-tight fit against the second edge of straightedge and noting the difference between the micrometer reading in this position and that obtaining previously with the square in contact with the first edge. One half of this difference divided by the horizontal normal distance between the axis of the micrometer and the axis of the tilt of the ball-feet *C*, of the support gives the angular error of the square per unit of length.

5.2.4 *Testing with Tilting Bar and Autocollimator*

The instrument comprises a vertical bar, pivoted on a horizontal axis slightly above its centre of gravity, carrying two discs of equal diameter and a plane mirror. The mirror, which is set with its plane at right angles to the plane in which the bar swings, forms the reflecting surface for an autocollimator used to measure the angle of tilt of the bar.

The work to be tested, such as the try-square shown in Fig. 18 is brought up to make contact with both discs and the autocollimator reading is noted. The square is then applied to the discs at the other side, as shown by the dotted lines. The bar is thus tilted into a different position and a reading is taken on the autocollimator. The difference between the readings is equal to twice the error in perpendicularity.

The upper disc should be capable of vertical adjustment in order that the instrument may deal with varying sizes of work. If, in addition, the lower disc can be adjusted, the perpendicularity of the inside edge of the blade to the bottom of the stock can be tested.

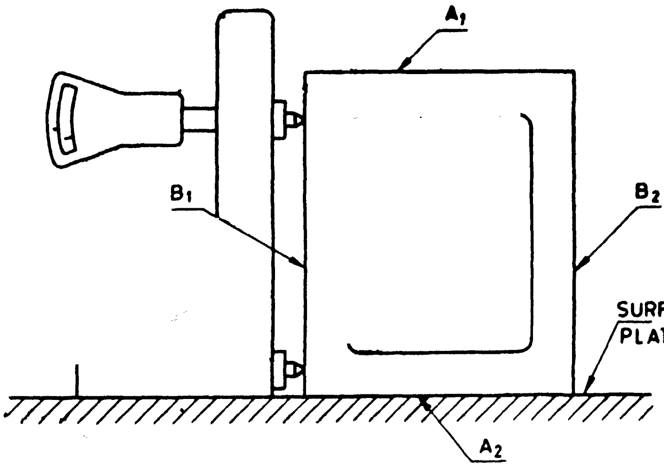


FIG. 16 METHOD OF TESTING PERPENDICULARITY OF BLOCK SQUARES

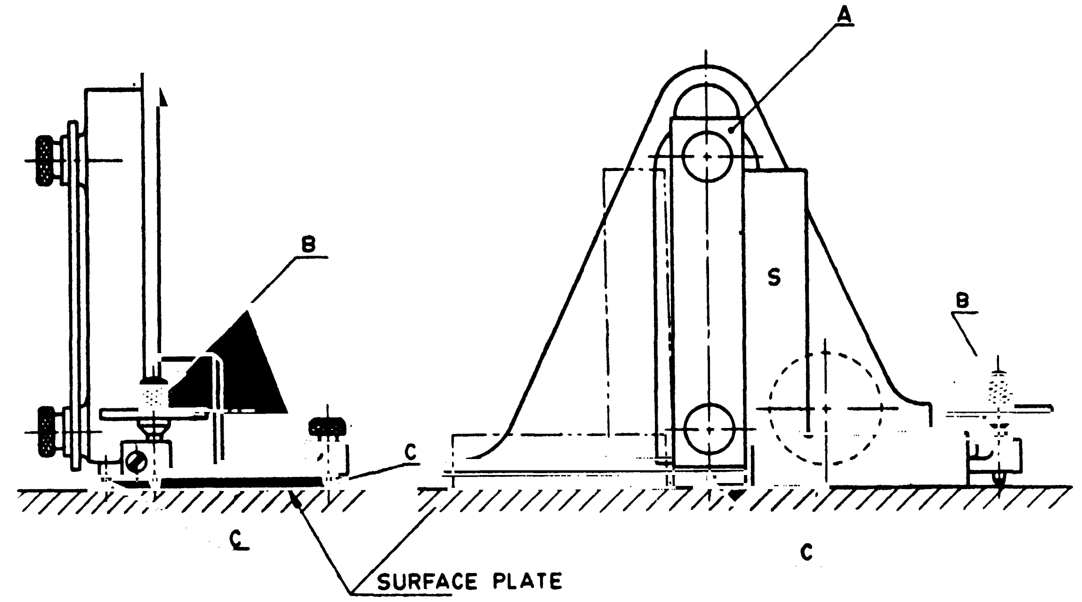


Fig. 17 Testing on a Tilting Squareness Tester

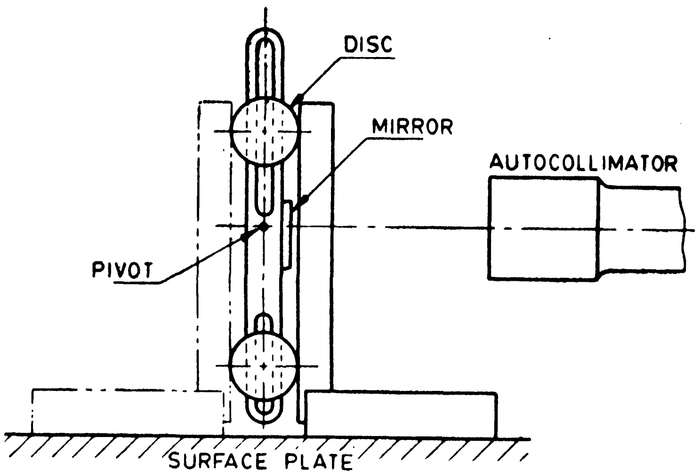


Fig. 18 Tilting Bar Method of Squareness Testing

5.2.5 *Testing with an Optical Square*

Occasions may arise wherein it may not be possible to align an autocollimator to obtain a reflection from the surface to be tested. In such cases, an optical square may often be employed. An example is shown in Fig. 19 where the perpendicularity of the vertical face to the base of the workpiece is to be checked.

The optical square is a constant-deviation prism which turns rays of light through 90 degrees without the necessity of setting it precisely in relation to the light. The actual angle is not exactly 90 degrees, but the error is only a second or two and is engraved on the body of the square, so that, if necessary for very precise measurements, allowance can be made for this slight variation.

Referring to the figure, the autocollimator is set to receive a reflection from the surface plate and the reading is noted. The work to be checked is then placed on the surface plate and the optical square put in position. If the vertical face of the work is accurately perpendicular with the base, the autocollimator reading will not alter; any change is a direct measure of the departure from perpendicularity.

5.2.6 *Testing of an Internal Right Angle*

Figure 20 shows how an autocollimator may be used to check the perpendicularity of an internal right angle. The instrument is arranged at an angle of approximately 45 degrees to receive reflections from both faces forming the right angle. If these are not sufficiently reflective, slip-gauges may be held against them as shown in the figure. If the faces are accurately perpendicular, only one reflection is seen in the autocollimator but any departure from perpendicularity causes two reflections.

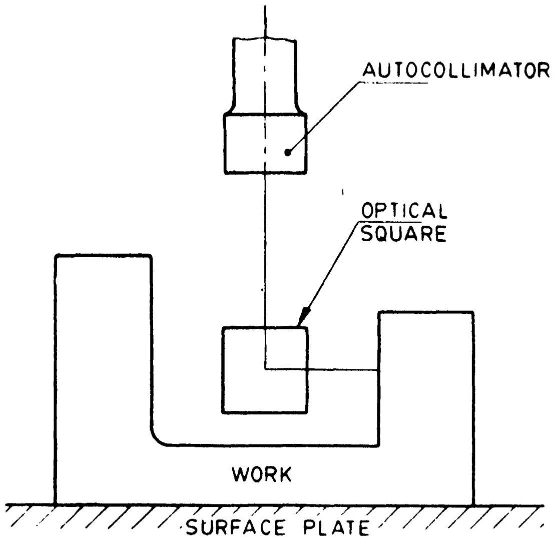


Fig. 19 Using an Optical Square to Test for Perpendicularity

5.2.7 *Testing on a Coordinate Measuring Machine*

Perpendicularity testing may be conveniently done on a three coordinate measuring machine, if the test item can be accommodated on it.

5.2.8 *Laser Interferometric Method*

Laser interferometer provides perpendicularity measuring capability by using the straightedge configuration in combination with a precision optical square (*see* Fig. 21).

The optical square bends the optical straightedge, defined by the Straightness reflector, precisely 90°. This enables the operator to make straightness measurements of two orthogonal axes with one optical set up.

The optical square is supplied with a reference mounting fixture that aids alignment of the square by positioning it to match the system's common optical centerline in both the horizontal and vertical orientations.

5.2.8.1 *Making perpendicularity measurements*

In the example shown X-axis out-of-straightness in the vertical plane is measured first. Then the optical square is positioned under the spindle axis to bend the optical straightedge 90° and the straightness interferometer and retroreflector are mounted in the spindle. The turning mirror is mounted on the square to complete the beam path to the laser head. Out-of-straightness in the same plane in the Z-axis is then measured (*see* Fig. 22).

A comparison of the two straightness measurements with respect to the 90° reference established by the optical square yields out-of-squareness between the X and Z axes.

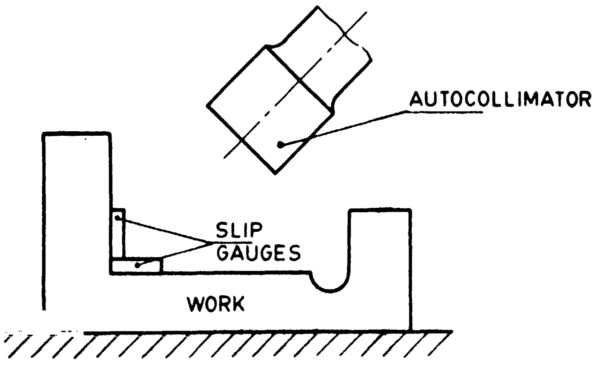


Fig. 20 Perpendicularity Testing of an Internal Right Angle

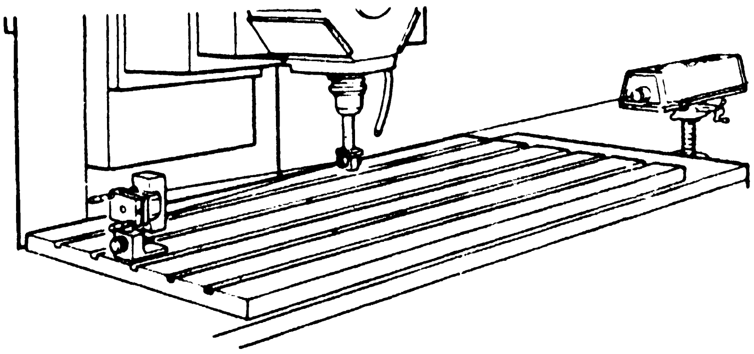


Fig. 21 X-Axis Vertical Straightness Measurement Set-Up

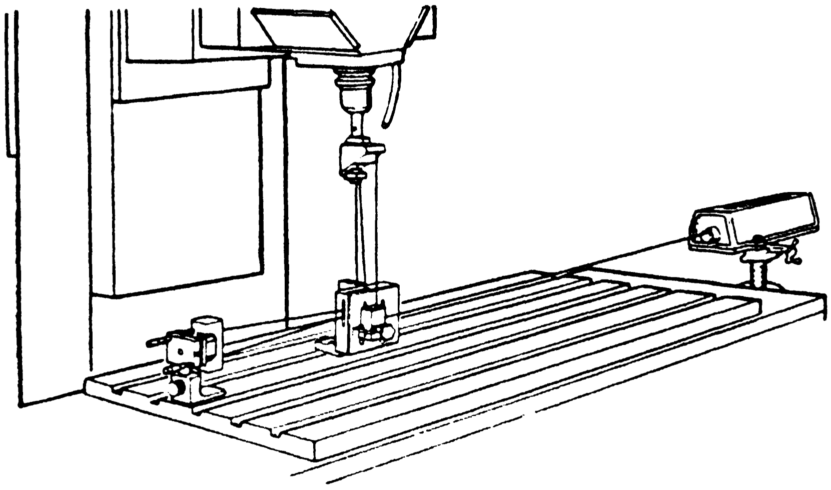


Fig. 22 Z-Axis Straightness and X-Z Axes Perpendicularity Measurement Set-Up

Standard Mark

The use of the Standard Mark is governed by the provisions of the *Bureau of Indian Standards Act, 1986* and the Rules and Regulations made thereunder. The Standard Mark on products covered by an Indian Standard conveys the assurance that they have been produced to comply with the requirements of that standard under a well defined system of inspection, testing and quality control which is devised and supervised by BIS and operated by the producer. Standard marked products are also continuously checked by BIS for conformity to that standard as a further safeguard. Details of conditions under which a licence for the use of the Standard Mark may be granted to manufacturers or producers may be obtained from the Bureau of Indian Standards.

Bureau of Indian Standards

BIS is a statutory institution established under the *Bureau of Indian Standards Act, 1986* to promote harmonious development of the activities of standardization, marking and quality certification of goods and attending to connected matters in the country.

Copyright

BIS has the copyright of all its publications. No part of these publications may be reproduced in any form without the prior permission in writing of BIS. This does not preclude the free use, in the course of implementing the standard, of necessary details, such as symbols and sizes, type or grade designations. Enquiries relating to copyright be addressed to the Director (Publications), BIS.

Revision of Indian Standards

Indian Standards are reviewed periodically and revised, when necessary and amendments, if any, are issued from time to time. Users of Indian Standards should ascertain that they are in possession of the latest amendments or edition. Comments on this Indian Standard may be sent to BIS giving the following reference:

Doc : No. LMD 05 (5151)

Amendments Issued Since Publication

Amend No.	Date of Issue	Text Affected

BUREAU OF INDIAN STANDARDS

Headquarters :

Manak Bhavan, 9 Bahadur Shah Zafar Marg, New Delhi 110002
Telephones : 331 01 31, 331 13 75

Telegrams : Manaksanstha
(Common to all Offices)

Regional Offices :	Telephone
Central : Manak Bhavan, 9 Bahadur Shah Zafar Marg NEW DELHI 110002	331 01 31 331 13 75
Eastern : 1/14 C. I. T. Scheme VII M, V. I. P. Road, Maniktola CALCUTTA 700054	87 86 62
Northern : SCO 445-446, Sector 35-C, CHANDIGARH 160036	53 38 43
Southern : C. I. T. Campus, IV Cross Road, MADRAS 600113	235 02 16
Western : Manakalaya, E9 MIDC, Marol, Andheri (East) BOMBAY 400093	632 92 95

Branches : AHMADABAD. BANGALORE. BHOPAL. BHUBANESHWAR. COIMBATORE. FARIDABAD. GHAZIABAD. GUWAHATI. HYDERABAD. JAIPUR. KANPUR. PATNA. THIRUVANANTHAPURAM.

Printed at New India Printing Press, Khurja, India